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(54) **DIFFERENTIAL PRESSURE FLOW SENSOR**

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(52) **U.S. Cl.** **73/861.52**; 73/861.42; 73/181; 73/182

(58) **Field of Search** 73/861.42, 861.52, 73/861.58, 861.63, 861.65, 181, 182, 170.14

(56) **References Cited**

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4,448,069	5/1984	Gibert .	
4,685,093 *	8/1987	Gill	367/89
4,920,808	5/1990	Sommer .	
5,412,984	5/1995	Okita .	
5,515,735	5/1996	Sarihan .	
5,583,289	12/1996	Wiggerman et al. .	
5,585,557 *	12/1996	Loschke et al.	73/170.14

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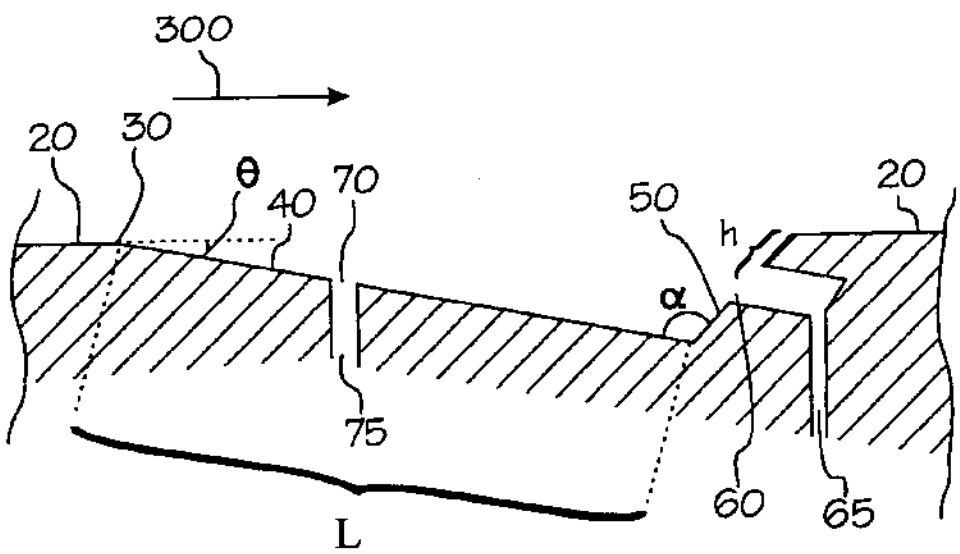
(57) **ABSTRACT**

The fluid flow meter of the present invention includes a ramp inclined to the surface of a vessel so as to form a recess in the surface. A dynamic port surface extends from the lower end of the ramp to the surface of the vessel. A dynamic port is formed in the surface of the vessel, and a static port is formed in the ramp. The differential pressure between the dynamic and static ports is measured and is related to the flow velocity of fluid over the surface. The inventive flow meter has advantages of reduced drag, reduced likelihood of fouling and reduced likelihood of impact damage compared to conventional flow meters.

25 Claims, 5 Drawing Sheets



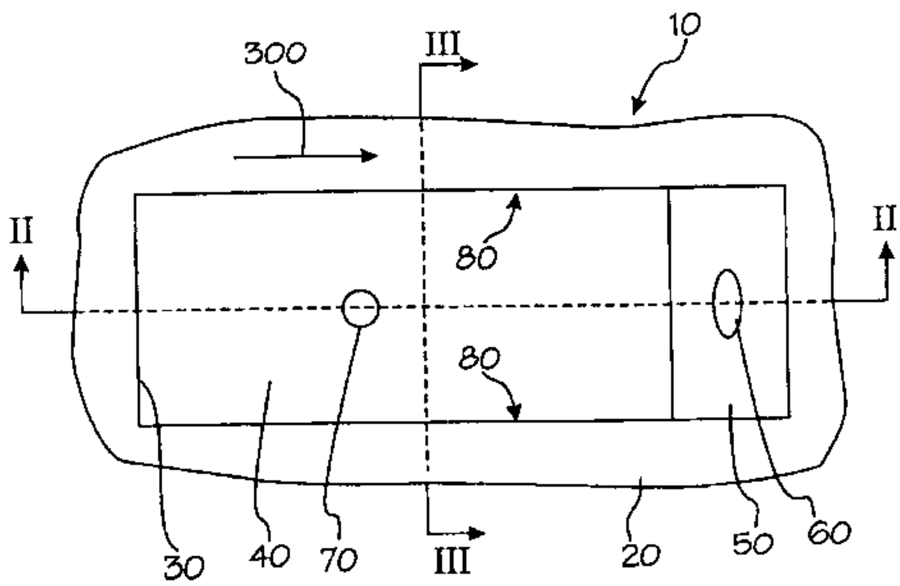
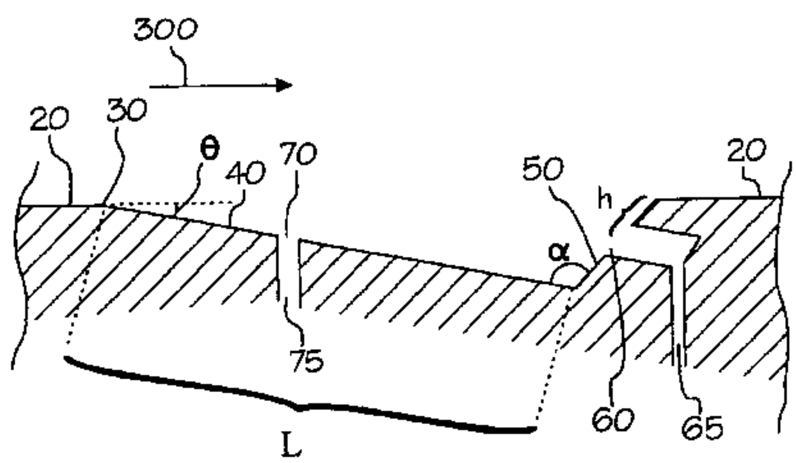

10
300
III
II
II
80
80
30
40
70
III
20
50
60

Fig. 1


300
20
30
θ
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70
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20
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α
75
60
65
L

Fig. 2

Fig. 3a

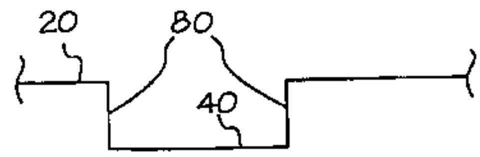


Fig. 3b

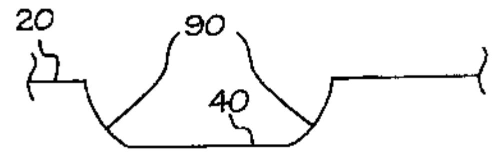


Fig. 3c

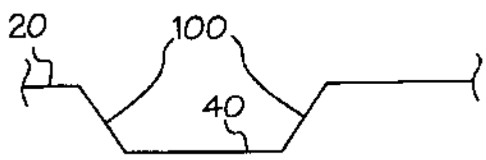


Fig. 3d

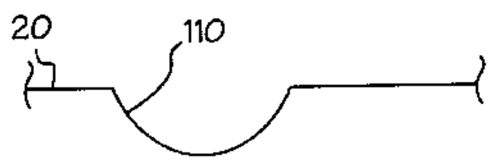


Fig. 3e

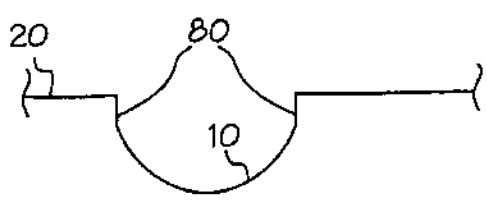


Fig. 3f

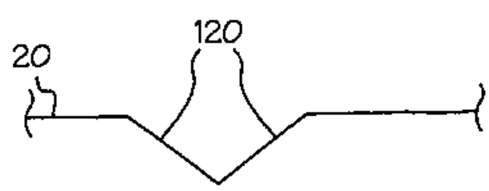


Fig. 4a

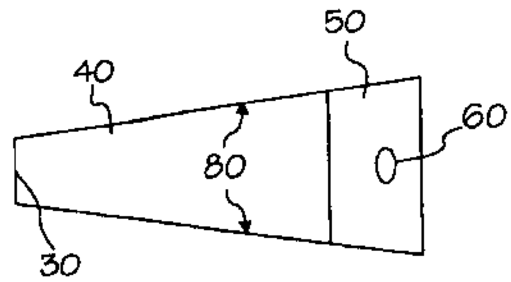
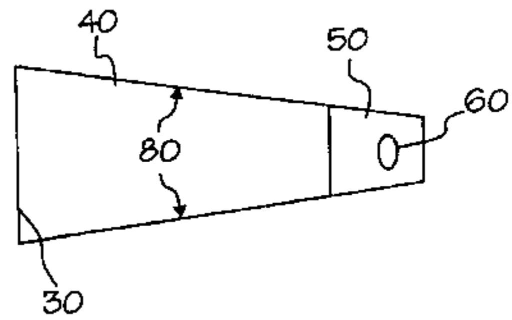


Fig. 4b



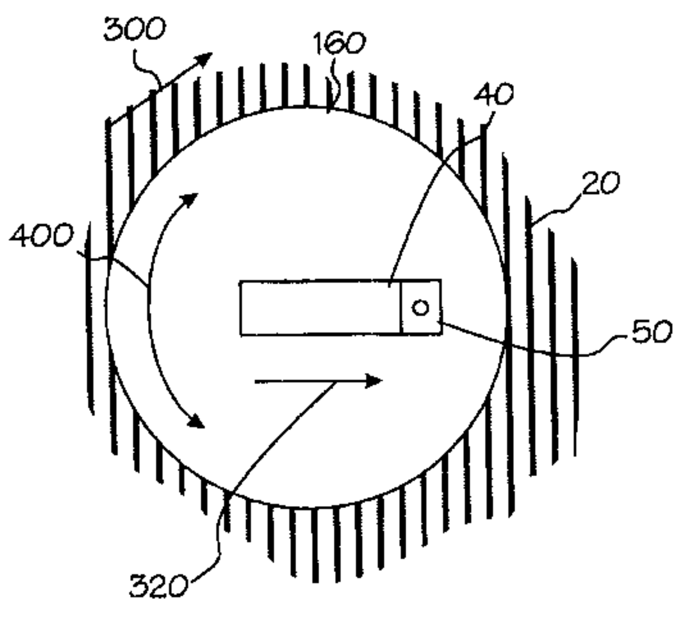


Fig. 6

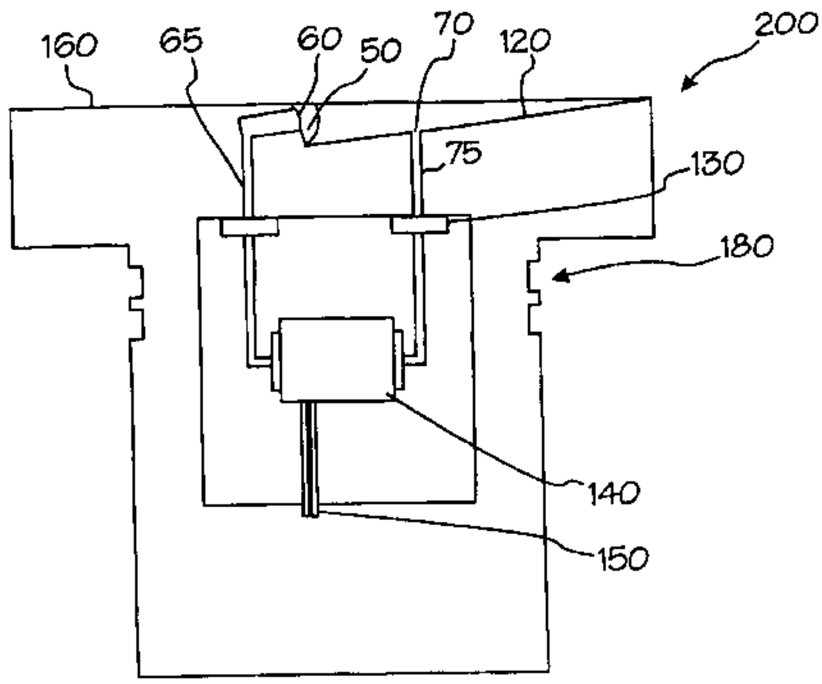


Fig. 5a

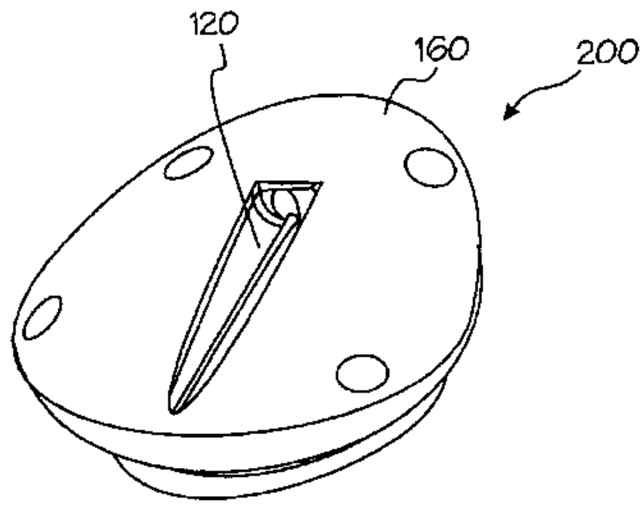
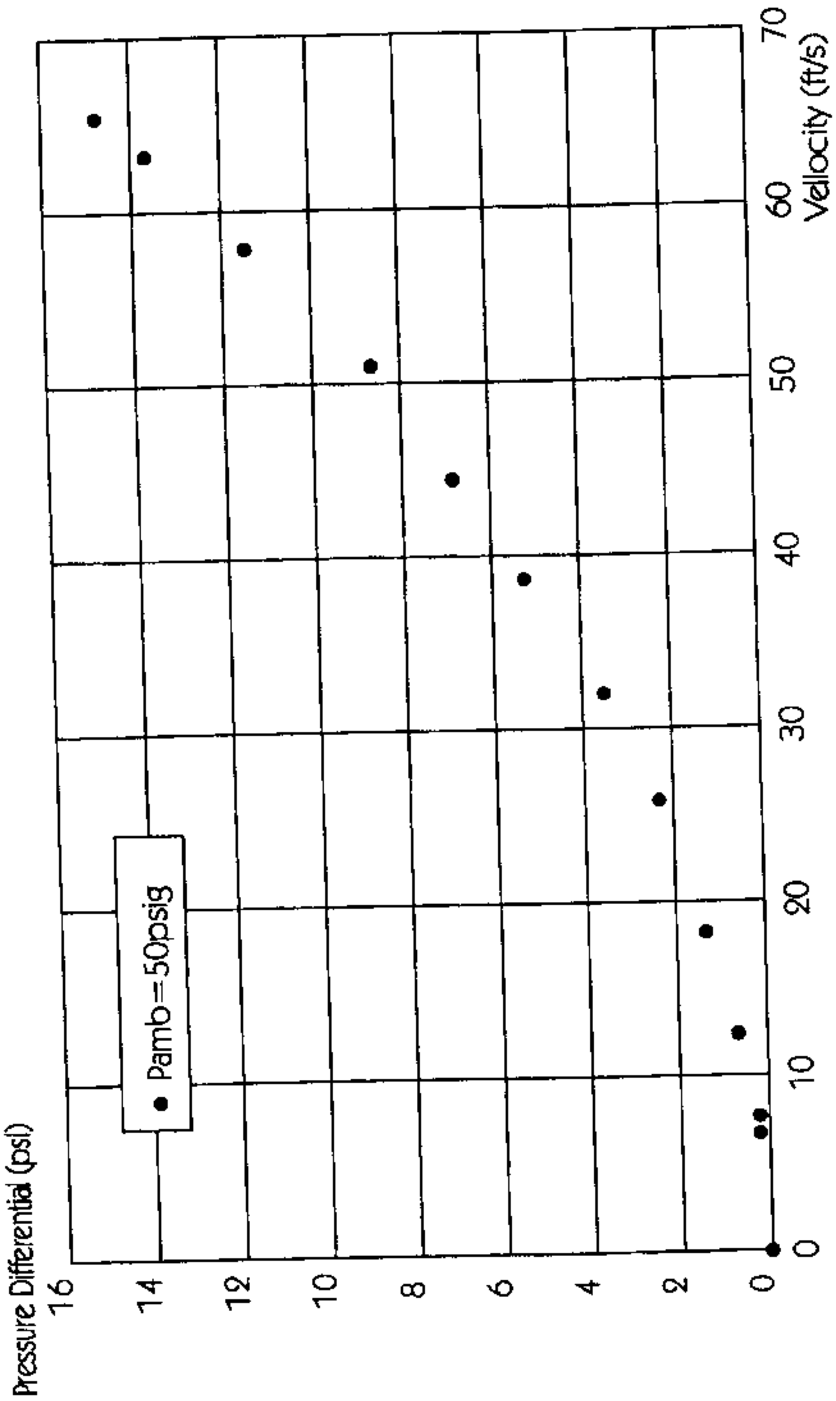


Fig. 5b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16
14
12
10
8
6
4
2
0
Velocity (ft/s)
0
10
20
30
40
50
60
70
Pamb=50psig

Fig. 7

DIFFERENTIAL PRESSURE FLOW SENSOR

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates generally to devices for measuring the speed of fluid flow using pressure differential, and more specifically to devices for measuring the speed of watercraft.

2. Description of the Related Art

A commonly used device for the measurement of the air speed of airplanes or water speed of vessels is the Pitot tube. Typically, a Pitot tube is oriented facing the direction of travel through the fluid (water or air), and is positioned at a distance from the surface of the vessel, so that the Pitot tube is outside the boundary layer of the flow and therefore experiences the full flow. The pressure in the Pitot tube increases as the speed of the fluid passing by the opening of the tube increases. The pressure of the Pitot tube is measured or compared differentially to the pressure in a static tube oriented perpendicularly to the direction of fluid flow to determine the speed.

A related device used in the measurement of fluid flow is the Stanton tube. The Stanton tube is typically mounted on the surface over which the fluid is flowing, and therefore is in the boundary layer. The pressure in the Stanton tube is less than would be observed for a Pitot tube outside the boundary layer, and the Stanton tube must therefore be calibrated for the particular surface where it is mounted. Stanton tubes are generally not used as speedometers for aircraft or water vessels.

While the use of Pitot tubes as speedometers or flow meters is common, Pitot tubes have several drawbacks, especially when used in marine applications. Because they are generally mounted sticking away from the surface of a vessel, Pitot tubes are subject to damage from bumping. Collision with or snagging of flotsam or submerged debris, for example, driftwood, marine animals, or seaweed, can disable a Pitot tube. Airplane Pitot tubes can be damaged while on the ground, or by bird strikes, etc., in the air.

Similarly, Pitot tubes are subject to fouling by particles entering the tube. Bugs, marine life, sediment, etc., may all potentially enter the Pitot tube leading to inaccurate readings or complete failure of the device.

In addition, Pitot tubes inherently impose drag on the vessel to which they are attached. While this drag is not usually a problem for ordinary airplanes or boats, it may well pose a problem is in high performance applications.

The following examples of the conventional art illustrate various speed measuring devices based on sensing fluid pressure. U.S. Pat. No. 3,978,725, to Hadtke, entitled Speedometer Particularly For Water Skis, describes a water ski with a Pitot-tube like device disposed on the underside of the ski. A flexible diaphragm transmits the pressure from a tube opening to a fluid inside the ski, and thereby to a speedometer on the ski. The Pitot-tube like device has the tube opening on a portion of a rib on the underside of the ski.

U.S. Pat. No. 4,448,069, to Gibert, entitled Airspeed Sensing Post For Determining Relative Velocity Of A Fluid And A Carrier, discloses an airspeed sensing post with a static pressure sensing device of a particular shape, such that the measurement of static pressure is not affected by pitch angle. This device uses a standard Pitot tube, and does not solve the problems of Pitot tubes addressed above.

U.S. Pat. No. 4,920,808, to Sommer, entitled Device And Method For Measuring The Flow Velocity Of A Free Flow In Three Dimensions, describes a rotationally symmetrical flow body with at least two sets of peripherally spaced openings in regions of different thickness along the side of the body. The velocity of flow along the body is determined by differences in the static pressure measured in the openings. This device takes the form of a symmetrical flow body probe which presumably is mounted on a vehicle such as an aircraft or rocket in a position to experience the full flow, that is, away from the body of the vehicle. Thus, this device does not solve many of the problems with Pitot tubes described above.

U.S. Pat. No. 5,412,984, to Okita, entitled Vessel Speed Measuring System For The Marine Propulsion Machine, describes a vessel speedometer for a marine propulsion system such as an outboard motor. The design incorporates a Pitot tube pressure intake port in the lower leading edge of the outboard motor. Various designs to prevent fouling of the intake port, including ridges and projections around the intake port, are illustrated. This apparatus is specifically designed for use on a propulsion apparatus, however, and the apparatus requires that the intake port directly face the flow of the water.

U.S. Pat. No. 5,515,735, to Sarihan, entitled Micromachined Flow Sensor Device Using A Pressure Difference And Method of Manufacturing The Same, describes a micromachined flow sensor using a pressure differential. This device is related to Venturi-type devices, and such a device must be placed directly in the fluid flow.

U.S. Pat. No. 5,583,289, to Wiggerman et al., entitled Marine Velocity Detection Device With Channel To Wash Out Debris, describes a marine speedometer in which the pressure sensing orifice is protected by the curvature of a top portion of a tunnel through which the water flows. The overall apparatus must be placed in the direct fluid flow, and is mounted to a transom of the watercraft. This detection device is therefore a relatively bulky appendage to the watercraft.

Based on my reading of the art, I believe that what is needed is a flow meter or speedometer which may be mounted flush on the surface of a vessel so as not to protrude from the vessel as the standard Pitot tube does. Although non-protruding flow meters which directly face the direction of flow are available, as in U.S. Pat. No. 5,583,289, it is often impractical or undesirable to mount a flow detector on the nose of a vessel, that is, on the surface normal to the flow. Thus, I believe that what is needed is a flow meter which moreover may be mounted on a side surface over which the fluid is flowing roughly parallel to the surface.

SUMMARY OF THE INVENTION

It is therefore an object of the present invention to provide an improved fluid flow meter.

It is a further object of the invention to provide an improved flow speedometer on a vessel.

It is a still further object of the invention to provide a flow meter which has reduced drag.

It is a yet further object of the invention to provide a flow meter which is more resistant to impact damage.

It is another object of the invention to provide a flow meter which is more resistant to fouling.

It is yet another object of the invention to provide a flow meter which can be mounted flush on the side of a vessel.

To achieve the above objects, the present invention provides a differential pressure flow meter for a vessel which includes a longitudinal recess angled to the surface of the vessel so as to form a ramp, and a dynamic port surface angled extending from the floor of the ramp to the surface. A dynamic port is formed in the dynamic port surface and is connected through a dynamic port channel to a pressure transponder. Optionally, a static port may be provided in the ramp or from the surface of the vessel, and the static port may be connected through a static port channel to the pressure transponder which is used to determine the differential pressure between the dynamic and static ports. The pressure in the dynamic port channel or differential pressure between the dynamic and static port channels is related to the flow rate of fluid across the surface of the vessel.

BRIEF DESCRIPTION OF THE DRAWINGS

A more complete appreciation of the invention, and may of the attendant advantages, thereof, will be readily apparent as the same becomes better understood by reference to the following detailed description when considered in conjunction with the accompanying drawings in which like reference symbols indicate the same or similar components, wherein:

FIG. **1** is a top plan view of an embodiment of the flow meter of the present invention;

FIG. **2** is a transverse cross-sectional view taken through II—II in FIG. **1**;

FIG. **3**(*a*) is a longitudinal cross-sectional view taken through III—III in FIG. **1**, and FIGS. **3**(*b*) through (*f*) are corresponding cross-sectional views of alternative embodiments of the invention;

FIGS. **4**(*a*) and (*b*) are top plan views of alternative embodiments of the invention;

FIGS. **5**(*a*) and (*b*) are cross-sectional and perspective views of a device incorporating the principles of the present invention;

FIG. **6** is an alternative embodiment of the present invention; and

FIG. **7** is a plot of differential pressure versus flow velocity for an Example of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to the drawings, an embodiment illustrating the general principles of the present invention is shown in FIGS. **1** and **2**, where FIG. **1** is a top plan view and FIG. **2** is a longitudinal cross-sectional view. As shown in FIG. **1**, the inventive device is installed in a region **10** of the surface **20** of a vessel. The vessel can be any object moving through a fluid, or around which a fluid is moving, such as a boat, airplane, land vehicle, torpedo, water flow meter, buoy, etc. The approximate direction of fluid flow across surface **20** of the vessel is indicated by arrow **300**. The device is formed in a recess in surface **20**. This recess begins at leading edge **30**, and is defined in this embodiment by walls **80**, ramp **40**, and dynamic port surface **50**. Thus the ramp extends from the surface and is inclined to the surface to form the recess. Dynamic port surface **50** therefore extends from the lower end of the ramp to the surface.

Formed in ramp **40** is static port **70** connected to static port channel **75**. Formed in dynamic port surface **50** is dynamic port **60**, which is connected to dynamic port channel **65**. Dynamic port **60** is therefore recessed relative to surface **20** of the vessel. Dynamic port **60** is preferably cylindrical, with the cylindrical axis oriented roughly parallel to ramp **40**. Dynamic port **60** is connected to dynamic port channel **65** which is in turn typically connected to a mechanical or electronic pressure transducer (not shown). The pressure in the dynamic port channel, analogously to the pressure in a Pitot tube, is related to the speed of fluid flow over the vessel. For situations in which the static pressure is not constant, such as vessels whose altitude or depth is varying (for example airplanes or submarines), the pressure differential between the dynamic port channel and the static port channel is measured and this value is related to the speed of the vessel.

The embodiment of the invention shown in FIGS. **1** and **2** has vertical walls **80**, as shown in transverse cross-section in FIG. **3**(*a*). However, many possible shapes of the recess will function, and several alternative embodiments are shown in FIGS. **3**(*b*) through (*f*). The ramp may be a single curved floor surface, or the ramp may have two side walls. In the embodiment of FIG. **3**(*b*), ramp **40** is flat, but walls **90** are curved and concave toward the exterior. In the embodiment shown in FIG. **3**(*c*), ramp **40** is flat, and walls **100** are angled from the vertical so as to slope into the recess. In the embodiment shown in FIG. **3**(*d*), the ramped portion of the recess is formed of a portion of a cylinder, and floor **110** is a circular section. In the embodiment shown in FIG. **3**(*e*), the recess is formed with vertical wall **80** and curved floor **10**. In the embodiment shown in FIG. **3**(*f*), the recess is formed by two angled walls **120**.

Likewise, the embodiment of the invention shown in FIGS. **1** and **2** has walls **80** which are parallel. An alternative embodiments is shown in FIG. **4**(*a*) in which walls **80** diverge from leading edge **30** to dynamic port surface **50**, and in another embodiment shown in FIG. **4**(*b*) walls **80** converge from leading edge **30** to dynamic port surface **50**. Also, since the bottom of the ramp descends from the vehicle surface, for some wall shapes, for example cylindrical walls, the pattern of intersection of the walls with surface **20** may appear to converge or diverge in an overhead plan view.

It will readily be appreciated that various combinations of the transverse cross-sections of FIG. **3** and the converging or diverging walls of FIG. **4** are possible. Design selection may be prompted by the material and production method of the device. For example, if the device is made of metal and is to be machined, it may be easiest to drill the recess, and a cylindrical section such as in FIG. **3**(*d*) may result. If the device is cast or molded, a greater variety of combinations may be readily achievable. It is to be understood that the exact shape of the device may be optimized by one skilled in the art, but that the present invention embraces a wide variety of designs.

The performance of the device will be affected by the value of various design parameters. Four important parameters are shown in FIG. **2**. Angle θ represents the angle of descent of ramp **40** of the recess relative to surface **20** of the vessel. L is the length of ramp **40** from leading edge **30** to dynamic port surface **50**. Angle α is the angle between dynamic port surface **50** and ramp **40**. Distance h is the distance along dynamic port surface **50** from surface **20** to the center of dynamic port **60**.

It will be appreciated that the these parameters are not entirely independent of each other. It is essential for the device that the dynamic port **60** be recessed below surface **20**, and the distance to which dynamic port **60** is recessed, given by parameter h, is limited by the depth of dynamic port surface **50**. The depth of dynamic port surface **50** is related geometrically to the angles θ and α and length L. In particular, if θ is small, a larger value of L is necessary to achieve the depth below surface **20** than with a larger value of θ.

Preferably, in devices of the present invention, the value of θ will be in the range of greater than 0° to approximately 30°, and more preferably in the range of greater than 0° to approximately 7°. The value of θ must be greater than 0°, or else there is no recess. However, very low values of θ may be used so long as L is great enough to allow sufficient depth of recess to position the dynamic port below surface **20**. Values of angle α are preferably in the range of approximately 75 to 135°, and more preferably in the range of approximately 90 to 110°.

The fluid flow measuring device of the present invention may be designed as an integral part of the surface of the vessel. Alternatively, it may be desirable to incorporate the device in a unit which can be installed in the vessel An example of such a unit is shown in FIG. **5**. Flow meter **200** of FIG. **5** can be seen to be of general cylindrical shape, with a cross-section along the cylindrical axis shown in FIG. **5**, and the housing of the flow meter is designed to be installed in a complementary hole formed in the surface a vessel (not shown). Top surface **160** of flow meter **200** is curved to match the curvature of the surface of the vessel and is flush with the surface of the vessel when flow meter **200** is installed. Flow meter **200** has a recess including ramp **120**, dynamic pressure port surface **50**, dynamic port **60** and static port **70** as described previously. Dynamic and static port channels **65** and **75** are connected through seals **130** to differential pressure sensor **140**, which is a micromachined diaphragm with embedded piezoresistive sensing elements. Electrical leads **150** transmit the electrical output of sensor **140** to a remote location, typically inside the vessel. Flow meter **200**, designed for use in water, has annular grooves **180** for retaining O-rings for providing a waterproof seal of the device into the vessel.

In principle, mechanical or electronic devices may be used to measure the pressure in the dynamic port channel or the differential pressure between the dynamic and static port channels. In practice, preferably an electronic transducer, as known in the art, will be used. The electronic output of the transducer may be output in an analog fashion and may be processed in an analog fashion so as to display the fluid flow speed or the speed of the vessel. Alternatively, the electronic output may be digitized and input to a microprocessor and digitally processed to allow digital display of the speed.

It will also be appreciated by one skilled in the art that the flow meter of the present invention may be modified to accommodate situations which commonly arise in fluid flow measurement. For example, FIG. 1 illustrates the case where the direction of fluid flow is parallel to the longitudinal direction of ramp **40**. A flow meter of the present invention used as a vehicle speedometer would generally be designed to orient the device in this way. However, the present invention could also be used in a flow meter, and in such a case the direction of flow might vary; that is, there may be cross-flow. Moreover, in some vehicles, there may be situations in which the direction of fluid flow across the surface changes direction.

In FIG. **6**, an embodiment of the invention is shown which compensates for changes of direction in fluid flow. The flow meter, including ramp **40** and dynamic port surface **50**, is formed in a circular unit mounted such that surface **160** of the circular unit is flush with surface **20** of the vessel, and is moreover mounted rotatably along the axis of the circular unit as shown by arrow **400**. Arrow **320** illustrates the longitudinal direction of ramp **40**, shown in FIG. **6** as different from fluid flow direction **300**. The circular unit also incorporates a drag element (not shown) such that when the fluid is flowing, the circular unit will tend to "weathervane" so as to align the direction of the ramp **320** with fluid flow direction **300**. When these directions are aligned, the device will indicate the correct fluid flow rate in direction **300**. A device could be incorporated to indicate the angular position of the servo ramp.

Alternatively, it will be appreciated that it is possible, for example, to incorporate two fixed flow meters of the present invention oriented orthogonally to each other, to indicate the two-dimensional flow velocity across the surface of the vessel.

In addition to the device embodiments of the present invention, the invention may also be generally expressed as a method for determining the velocity of fluid flow over a surface of an object. First, it is necessary to provide a ramp inclined into the surface so as to form a recess and to provide a dynamic port surface and a dynamic port as described in the above embodiments. In addition, a static port may be provided in the ramp or elsewhere on the object surface for measurement of the static pressure. Next, the dynamic pressure is measured as a function of known fluid flow velocity over the surface of the object. Alternatively, if a static port is provided, the pressure differential between the dynamic and static ports may be measured. In this way, a calibration is obtained between the dynamic pressure or differential pressure and the flow velocity. Finally, any flow velocity may then be determined from the dynamic pressure or the differential pressure using this calibration. Using this method, flow velocity may be measured in any surface which can be modified to provide the recess and measurement means.

The following Example describes test results for an exemplary embodiment of the above invention which has been reduced to practice, and the invention is not limited to this embodiment.

EXAMPLE

An Example of a flow meter of the general design shown in FIG. **5** was constructed of aluminum, with approximate overall diameter of 2.5 inches. The device was subjected to water flow tunnel tests, and the differential pressure was measured between the dynamic pressure port channel and the static port channel. A plot of differential pressure versus flow velocity is seen in FIG. **7**. The differential pressure increases in an approximately parabolic manner which readily allows interpolation of the velocity from the observed differential pressure. Thus, this device could be used as a flow meter or watercraft speedometer over this velocity range.

The device of the present invention can in principle be used as a fixed flow meter for determining the flow velocity of a fluid, or as a speedometer for a vehicle. As a flow meter, applications could include water flow monitoring in rivers, oceanography, etc., or in wells. As a speedometer, the present invention can in principle be used for airspeed measurement in airplanes, missiles, etc., or for water speed measurement in boats, submarines, torpedoes, etc. In principle, the device could be used in amphibious vehicles as well.

While particular embodiments of flow meter have been described, it is to be understood that the present invention is not limited to these embodiments. Various changes and modifications may be made without departing from the spirit and scope of the invention, as defined by the appended claims.

What is claimed is:

1. A fluid flow meter in the surface of a vessel, comprising:

a ramp connected to and extending longitudinally from a surface of a vessel exposed to fluid flow at a first end of the ramp to an opposite end of the ramp, said ramp inclined at a first angle to the surface to form a recess in the surface of the vessel;

a port member having a surface extending from said opposite end of the ramp, said dynamic port surface being oriented at a second angle to said ramp, wherein said second angle comprises less than about 180 degrees between said ramp and said surface, said surface having a dynamic port formed therein, the axis of said dynamic port oriented approximately parallel to said ramp; and

a pressure measurement device connected to the dynamic port, for measuring the dynamic pressure caused by a flow of fluid in a direction roughly parallel to the surface of the vessel exposed to fluid flow.

2. The fluid flow meter of claim 1, further comprising:

a static port formed in the ramp, said static port connected to the pressure measurement device; and

said pressure measurement device being a differential pressure measurement device for measuring the difference in pressure between the dynamic and static port.

3. The fluid flow meter of claim 1, further comprising:

a static port formed in the surface of the vessel, said static port connected to the pressure measurement device; and

said pressure measurement device being a differential pressure measurement device for measuring the difference in pressure between the dynamic and static port.

4. The fluid flow meter of claim 1, said ramp having a cylindrical shape.

5. The fluid flow meter of claim 1, said ramp comprising two side walls having upper edges adjoining the surface of the vessel.

6. The fluid flow meter of claim 5, said ramp further comprising a floor connecting the lower edges of the two side walls.

7. The fluid flow meter of claim 6, said side walls being flat and perpendicular to the surface.

8. The fluid flow meter of claim 6, said side walls being curved and concave toward the exterior of the vessel.

9. The fluid flow meter of claim 6, said floor being curved and concave toward the exterior of the vessel.

10. The fluid flow meter of claim 6, said walls being flat and angled to the surface of the vessel so as to slope into the recess.

11. The fluid flow meter of claim 1, said first angle being greater than 0° and less than approximately 30°.

12. The fluid flow meter of claim 11, said first angle being less than approximately 7°.

13. The fluid flow meter of claim 1, said second angle being in the range of approximately 75° to 135°.

14. The fluid flow meter of claim 13, said second angle being in the range of approximately 90° to 110°.

15. The fluid flow meter of claim 1, said pressure measurement device being a micromachined diaphragm with embedded piezoresistive sensing elements.

16. The fluid flow meter of claim 2, said pressure measurement device being a micromachined diaphragm with embedded piezoresistive sensing elements.

17. The fluid flow meter of claim 5, said side walls converging toward the dynamic port surface.

18. The fluid flow meter of claim 5, said side walls diverging toward the dynamic port surface.

19. A fluid flow meter for installation in a vessel, comprising:

a housing for installing in a complementary hole in the vessel, said housing comprising:

a top surface of curvature matching the curvature of a surface of a vessel exposed to fluid flow;

a ramp connected to and extending from said top surface at a first end of the ramp longitudinally to an opposite end of the ramp, said ramp inclined at a first angle to the top surface to form a recess in the top surface;

a port member having a surface extending from said opposite end of the ramp, said surface being oriented at a second angle to said ramp, said second angle comprises less than about 180 degrees between said ramp and said surface, said surface having a dynamic port formed therein, the axis of said dynamic port oriented approximately parallel to said ramp;

a static port formed in the ramp; and

a differential pressure sensor connected to said dynamic and static ports.

20. The fluid flow meter of claim 19, further comprising:

electrical leads extending from the pressure sensor to the interior of the vessel, for transmitting an electrical output of the sensor.

21. The fluid flow meter of claim 19, said housing further comprising:

an O-ring seal on a lower portion of the housing, for sealing the flow meter in the hole in the vessel.

22. The fluid flow meter of claim 19, further comprising:

the top surface of said housing being circular for fitting in a circular hole in the vessel.

23. The fluid flow meter of claim 22, further comprising:

said housing being rotatably mounted along the axis of the circular top surface; and

the top surface of said housing further comprising a drag element, for allowing the housing to weathervane with changes in the fluid flow direction.

24. A method of measuring fluid flow velocity above the boundary layer and across the surface of an object, comprising the steps of:

providing a ramp connected to a surface of an object exposed to fluid flow inclined to the surface so as to form a recess;

providing a dynamic port in a port member having a surface extending from the recessed end of the ramp at an angle comprising less than about 180 degrees between said ramp and said surface;

determining a calibration of the dynamic pressure in the dynamic port as a function of known fluid flow velocity; and

interpolating the value of an unknown fluid flow velocity from said calibration.

25. A method of measuring fluid flow velocity above the boundary layer and across the surface of an object, comprising the steps of:

providing a ramp connected to a surface of an object exposed to fluid flow inclined to the surface so as to form a recess;

providing a dynamic port in a port member having a surface extending from the recessed end of the ramp at an angle comprising less than about 180 degrees between said ramp and said surface;

providing a static port in the ramp;

determining a calibration of the differential pressure between the static and dynamic pressures as a function of known fluid flow velocity; and

interpolating the value of an unknown fluid velocity from said calibration of the differential pressure.

* * * * *

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US006328831B1

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Wagaman

(54) **GAS-GENERATING LIQUID COMPOSITIONS (PERHAN)**

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(73) Assignee: **The United States of America as represented by the Secretary of the Navy**, Washington, DC (US)

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(21) Appl. No.: **09/447,271**

(22) Filed: **Nov. 23, 1999**

(51) **Int. Cl.**^{7} **C06B 31/00**
(52) **U.S. Cl.** **149/45**
(58) **Field of Search** 149/45–108.8

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4,527,389	*	7/1985	Biddle et al.	60/207
5,607,181		3/1997	Richardson et al. .	
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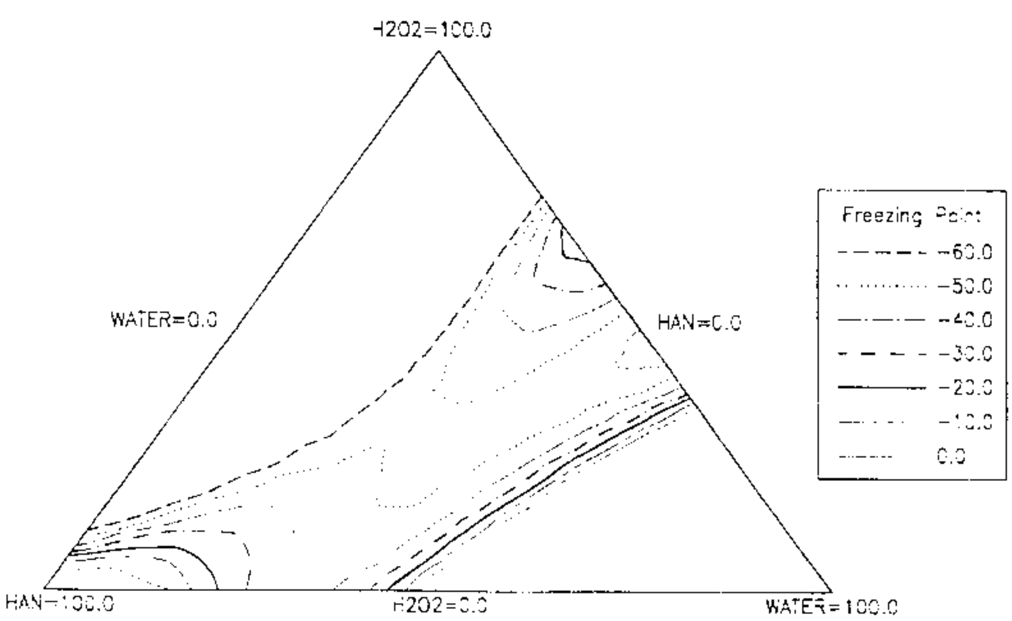
(57) **ABSTRACT**

A family of water-based, gas-generating liquid compositions is described. A composition of the present invention includes: hydrogen peroxide, hydroxylammonium nitrate, and water. Compositions of the present invention may be mixed with fuels to make monopropellants or used in bipropellant or hybrid systems. Alternate uses of the present invention include breathable gas generation or use as an oxygen source in welding.

22 Claims, 2 Drawing Sheets

Freezing Points for PERHAN Formulations



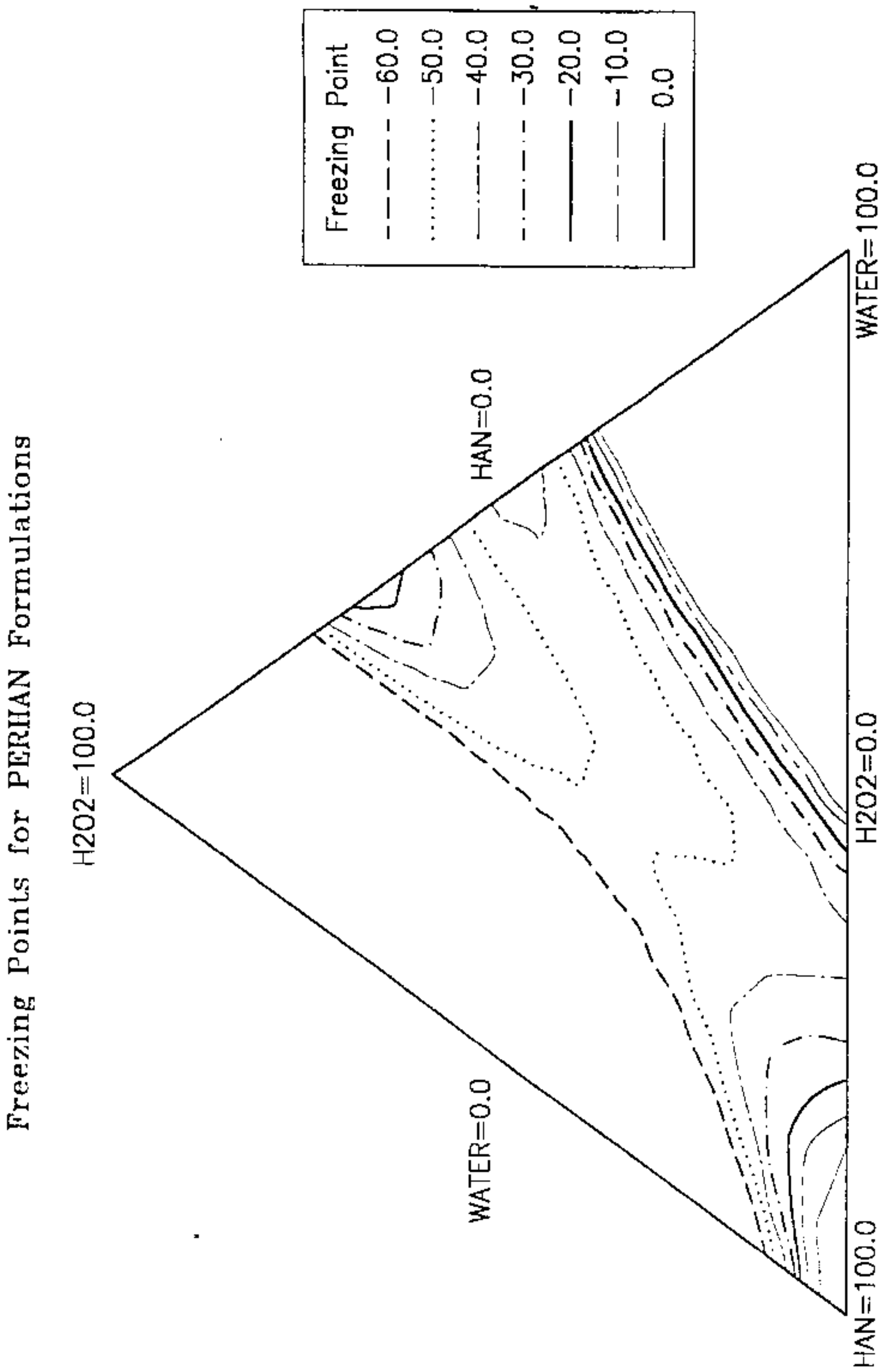
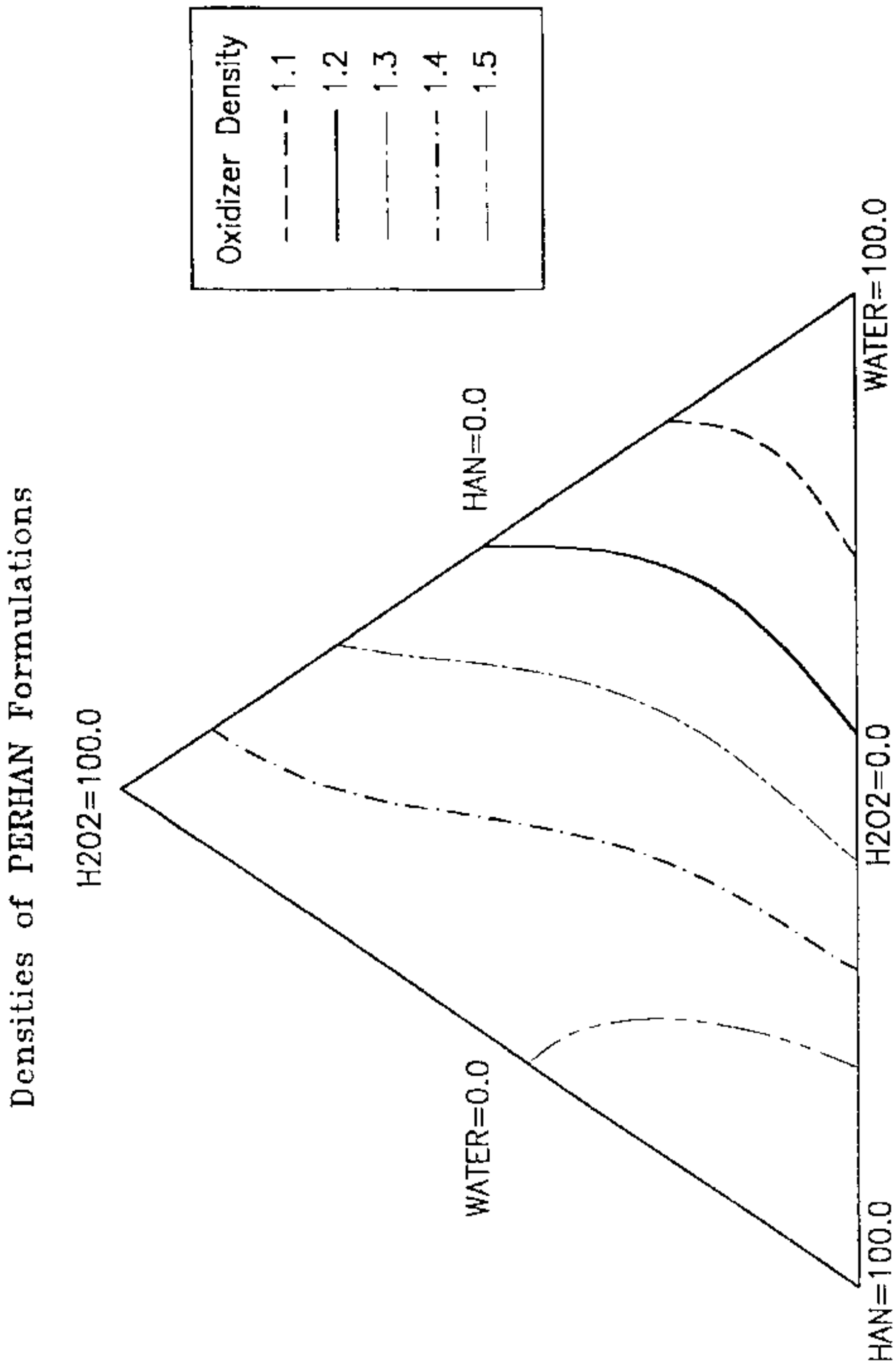

Freezing Points for PERHAN Formulations
Freezing Point
-60.0
-50.0
-40.0
-30.0
-20.0
-10.0
0.0
H2O2=100.0
HAN=0.0
WATER=100.0
H2O2=0.0
WATER=0.0
HAN=100.0

FIG-1


Densities of PERHAN Formulations
Oxidizer Density
1.1
1.2
1.3
1.4
1.5
H2O2=100.0
HAN=0.0
WATER=100.0
H2O2=0.0
WATER=0.0
HAN=100.0

FIG–2

GAS-GENERATING LIQUID COMPOSITIONS (PERHAN)

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to energetic and gas-generating compositions, and in particular to oxidizing compositions.

2. Description of the Related Art

There are numerous applications for gas-generating compositions. Energetic gas-generating compositions are commonly used, for example, in rocket propulsion systems as well as torpedos, safety air bags, etc. Oxygen-generating compositions also have utility in breathable air generators and underwater welding.

Of particular interest among these compositions are those which are liquids, in particular liquids which are oxidizers. Liquids are necessary for many propulsion systems since they can be pumped, and liquids are in general easier to handle and store than solids. The most commonly used liquid oxidizers for rocket propulsion have generally been liquid oxygen (LOX), inhibited red fuming nitric acid (IRFNA), hydrogen peroxide (H_2O_2), aqueous hydroxylammonium perchlorate (HAP) and nitrogen tetroxide (NTO). Each of these liquid oxidizers has problems associated with use. For example, LOX requires cryogenic storage and is dangerous when spilled. IRFNA, NTO and H_2O_2 also have handling and toxicity problems. HAP offers some advantages, but suffers from the presence of hydrochloric acid in the generated gas. Most of the liquid oxidizers in current use present a vapor toxicity or contact hazard, and are hypergolic, that is, spontaneously combusting, in the presence of fuels.

Thus, there are in fact a limited number of available choices of liquid oxidizers. That there is a need to fill the technology "gap" in liquid oxidizers of the contemporary art is seen, for example, in the following articles. In Mul, et al., *Search For New Storable High Performance Propellants*, (AIAA-88-3354, AIAA/ASME/SAE/ASEE 24th Joint Propulsion Conference, Boston, July 1988), the authors discuss the need for storable, non-cryogenic propellants with better performance properties. They discuss nitric acid, NTO and hydrazinium perchlorate as storable oxidizers.

Another problem with the available liquid oxidizers is that they are mostly limited to a single composition, and thus a single set of performance and physical properties. That is, they are not formulated to achieve different values of performance and physical parameters. Thus, variation of performance properties of propellant systems using these oxidizers can only be achieved by varying the composition of the fuel, thus limiting design options.

Anderson, W., et al., *Low Cost Propulsion Using A High-Density, Storable, and Clean Propellant Combination*, discuss the need for nontoxic, storable, restartable, throttleable and high density impulse systems for rocket motors. They suggest the use of high concentration hydrogen peroxide as a propellant. Although the authors describe hydrogen peroxide as nontoxic, direct human contact with hydrogen peroxide is extremely dangerous.

Rusek, J., *New Decomposition Catalysts And Characterization Techniques For Rocket-Grade Hydrogen Peroxide J. of Propulsion and Power*, 1996, 12, 574–579, discusses the use of hydrogen peroxide as a rocket propellant, both as a monopropellant and as an oxidizer with hydrazine hydrate methyl alcohol fuel.

Gas-generating systems in other applications also have problems associated with them.

For example, chlorate-based "chlorate candle" oxygen generators are used for emergency breathable oxygen in some airplanes and in welding applications. Because of the solid nature of the sodium chlorate, many of these devices cannot be turned off once triggered, and the heat production from such a device can prove to be a fire hazard. A liquid-based oxygen generator might overcome this problem. Moreover, chlorate-based devices typically produce some byproduct chlorine, which is toxic, in the breathable gas, and do not produce any diluent for the generated oxygen.

Examples of liquid gas-generating and explosive compositions of the contemporary art are seen in the following U.S. Patents. U.S. Pat. No. 3,561,533, to McKinnell, entitled Controlled Chemical Heating Of A Well Using Aqueous Gas-In-Liquid Foams, describes a two-component hypergolic reaction system in which an aqueous foam of hydrazine or dimethylhydrazine and an aqueous foam of hydrogen peroxide are mixed. The system is used to heat oil wells.

U.S. Pat. No. 3,790,415, to Tomic, entitled Chemical Foaming And Sensitizing Of Water-Bearing Explosives With Hydrogen Peroxide, describes addition of hydrogen peroxide as a foaming agent/sensitizer to water-bearing explosives having ammonium nitrate and fuel. Here, the hydrogen peroxide is added to the thickened or emulsified explosive mixture, and decomposes in the formulation to provide oxygen bubbles for foaming before the mixture is detonated.

U.S. Pat. No. 4,047,988, to Weill et al., entitled Liquid Monopropellant Compositions, describes a monopropellant which is an aqueous solution of a secondary or tertiary amine, and an oxidizer such as perchloric or nitric acid. Hydrogen peroxide is also mentioned as a possible oxidizer. Here, the amine apparently serves as the fuel in the monopropellant. Properties of the compositions including low freezing temperature, and use as a torpedo propellant, are described.

U.S. Pat. No. 5,607,181, to Richardson et al., entitled Liquid-Fueled Inflator With A Porous Containment Device, describes an automotive airbag inflator using a liquid monopropellant composed of a hydroxylamine nitrate (HAN)/triethanolamine nitrate (TEAN) water system. A system with hydrazine and hydrogen peroxide as liquid fuel components is also mentioned. HAN is a relatively expensive component, however. Moreover, TEAN serves as a fuel in this mixture, so the mixture probably cannot serve as a general oxidant for other fuels.

In addition to the above patents, U.S. Statutory Invention Registration No. H1,768, to

Mueller et al., entitled *Oxidizing Agent*, describes liquid oxidizers comprising water, hydroxylammonium nitrate, and ammonium nitrate or hydrazine mononitrate. Two oxidizing agents designated OXSOL 1 and OXSOL 2 are described. Discussed applications include use in gas generators for air bags, rocket propellants and torpedo propellants.

A document entitled *Advanced Chemical Propulsion Systems* discusses the need to replace hydrazine as a fuel, and suggests use of HAN/TEAN in a catalytic thruster. As noted above, HAN is relatively expensive, and HAN/TEAN system probably cannot be used as a general oxidant with other fuels.

An additional examples of a possible utility of a gas-generating system is seen in Berezovsky, *Pyrogen Fire*

Suppression System-Marine & Vehicle Applications, dated August 1997, which describes a fire extinguishing system (PyroGen) which is pyrotechnic-driven. The system produces an aerosol, and the composition of the system is not disclosed.

Based on my reading of the contemporary art, I have decided that what is needed is a gas-generating liquid composition which can be used as an oxidizer, and which has low cost, low toxicity and excellent handling properties.

SUMMARY OF THE INVENTION

It is therefore an object of the present invention to provide improved gas-generating liquid compositions.

It is also an object of the invention to provide improved liquid oxidizers for use in monopropellant and bipropellant systems.

It is another object of the invention to provide improved liquid compositions for generation of breathable air.

It is yet another object of the invention to provide gas-generating liquid compositions which have low cost.

It is still another object to provide gas-generating liquid compositions from readily available components.

It is a further object to provide gas-generating liquid compositions which have low vapor and skin toxicity.

It is a yet further object to provide gas-generating liquid compositions which have a low explosion hazard.

It is a yet still further object to provide compositions having excellent handling and storage characteristics, such as low corrosivity.

It is an additional object to provide gas-generating liquid compositions which are easy to prepare.

It is a yet additional object to provide gas-generating liquid compositions allowing ready production of customized formulations.

It is a still additional object of the invention to provide a gas-generating liquid having a low freezing point.

It is yet another object of the present invention to provide a gas-generating liquid which has high density and high energy density.

It is yet another object of the invention to provide a gas-generating liquid which is "green", that is, disposable without damage to the environment.

It is still another object of the invention to provide a gas-generating liquid which allows water-based cleanup of spills.

These objects are achieved in the present invention which provides a family of water-based gas-generating liquid compositions which may be used in rocket propulsion, torpedo propellants, air bags, and other applications. Applications also include use in oxygen generators and in fuel cells.

The general composition of the water-based gas-generating liquid of the present invention includes: hydrogen peroxide, hydroxylammonium nitrate (HAN) and water. Generally, the water concentration (that is, content) in the gas-generating liquid will be in the range of approximately 10 to 50 percent by weight (w/w-%), and the water concentration may be in the range of 15 to 30 w/w-%. Generally, the hydroxylammonium nitrate concentration will be in the range of approximately 20 to 70 w/w-%, and may be in the range of approximately 30 to 60 w/w-%. The concentration of hydrogen peroxide will generally be in the range of approximately 15 to 50 w/w-% and may be in the range of approximately 25 to 40 w/w-%. The gas-generating liquid composition of the present invention may have additional components, such as a colorant, an odorant, a gelant, a thixotropic agent, a surfactant, or a burning rate modifier.

In one embodiment, the gas-generating liquid compositions of the present invention may be added to a fuel to form a monopropellant. In another embodiment of the present invention, the gas-generating liquid composition may consist essentially of hydrogen peroxide, hydroxylammonium nitrate and water. Here, "consists essentially of" means that this composition has no added fuel, nor other component substantially affecting the energy content, freezing point, or density of the composition. Such a composition may have minor additional components, such as a colorant, an odorant, a gelant, a thixotropic agent, a surfactant, or a burning rate modifier, which do not substantially affect these parameters.

In addition to the compositions of the present invention, the invention also includes methods of use of the compositions. Specifically, the compositions of the present invention can be used for generating gas by passing the compositions through a solid catalyst bed, heating the compositions, or adding catalyst to the compositions. The compositions can also be mixed with a fuel to form monopropellants or can be used in bipropellant and hybrid rocket systems.

BRIEF DESCRIPTION OF THE DRAWINGS

A more complete appreciation of the invention, and many of the attendant advantages, thereof, will be readily apparent as the same becomes better understood by reference to the following detailed description when considered in conjunction with the accompanying drawings in which like reference symbols indicate the same or similar components, wherein:

FIG. 1 is a response surface diagram illustrating freezing points of compositions of the present invention; and

FIG. 2 is a response surface diagram illustrating densities of compositions of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

The gas-generating liquid compositions of the present invention are a family of compositions which the inventor refers to as PERHAN. The general composition of the water-based gas-generating liquid of the present invention includes: hydrogen peroxide, hydroxylammonium nitrate and water. The invention may also comprise any of a number of additives, and may comprise a fuel.

The present invention includes a family of compositions with varying amounts of hydrogen peroxide, hydroxylammonium nitrate and water. Preparation of the compositions of the present invention can generally be achieved simply by the mixing the ingredients of the invention. Generally, the water concentration (that is, content) in the gas-generating liquid will be in the range of approximately 10 to 50 percent by weight (w/w-%), and the water concentration may be in the range of 15 to 30 w/w-%. Generally, the hydroxylammonium nitrate concentration will be in the range of approximately 25 to 70 w/w-%, and may be in the range of approximately 30 to 60 w/w-%. The hydrogen peroxide will generally be in the range of approximately 15 to 50 w/w-% and may be in the range of approximately 25 to 40 w/w-%. Different compositions will have different values of parameters relevant to the use of the invention, and thus customized compositions of the present invention may be prepared.

Among the advantages of the present invention are the low freezing point achievable in some compositions. An important parameter of liquid gas-generating compositions is the freezing point. At temperatures below the freezing point, solids appear in the liquid, affecting many aspects of handling the liquid, for example, the ability to pump the liquid. In the present patent application, the term "freezing point" is taken to be the temperature below which any precipitation occurs in a gas-generating liquid composition. If, repeatedly, cooling the liquid below the freezing point leads to precipitation and heating to a temperature above the freezing point allows redissolution, then the freezing point can be considered to be reasonably well defined. Generally, it is desirable that a gas-generating liquid composition be selected to have a freezing point below the ambient temperature at which the composition will be used and stored.

In order to determine the freezing point of a composition of the present invention, the following method is used. This method may be easily performed by one skilled in the art. A sample of the liquid composition of interest is placed in a 16-mm test tube along with the bulb of a glass thermometer of appropriate temperature range. Generally, enough liquid to give a height of ¾" is used. The bottom portion of the test tube is then placed in a dry ice-ethanol bath in a Dewar flask. The sample is cooled until crystals appear visually in the liquid sample. The test tube is then removed from the bath and is warmed as necessary with stirring by the thermometer, until the crystals redissolve, noting the temperature at which redissolution occurs. The test tube is then cooled again in the bath to the noted temperature. While stirring, the test tube is cooled until crystals appear, and then removed to allow warming and dissolution. This is performed repeatedly until the temperature where a slight cooling causes crystal formation and slight warming allows dissolution is found, and this temperature is recorded as the freezing point.

Another advantage of the present invention is the high density achievable in some of the inventive compositions. Density is an important contribution to the energy content of a given composition, as more mass per unit volume allows more chemical energy per unit volume. Likewise, greater density also allows greater amount of gas generated per unit volume of liquid. In the present invention, density is presented as specific gravity, that is, a unitless value relative to the density of water at 4° C. Here, densities of the liquid compositions are measured at room temperature, about 20° C., using a commercial hydrometer, by method well known in the art.

In Table I, freezing-point data and density data for selected compositions of hydrogen peroxide, hydroxylammonium nitrate and water. The table includes some data for compositions with no hydrogen peroxide or hydroxylammonium nitrate for comparison to compositions of the present invention and for better understanding of the properties of the present invention.

TABLE I

Observed Freezing Point (° C.) and Density (g/cc) for Various Compositions of Hydrogen Peroxide, Hydroxylammonium Nitrate and Water

Hydroxyl-ammonium Nitrate	Hydrogen Peroxide	Water	Freezing Point	Density
[illegible]	[illegible]	[illegible]	−15	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	−38	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	−52	[illegible]

TABLE I-continued

Observed Freezing Point (° C.) and Density (g/cc) for Various Compositions of Hydrogen Peroxide, Hydroxylammonium Nitrate and Water

Hydroxyl-ammonium Nitrate	Hydrogen Peroxide	Water	Freezing Point	Density
0.743	0.056	0.201	−28	1.507
0.669	0.1	0.231	−37	1.472
0.827	0	0.173	−8	1.545
0.819	0	0.181	−10	1.53
0.803	0	0.197	−16	1.513
0.788	0	0.212	−21	1.497
0.752	0	0.248	−30	1.462
0.689	0	0.311	−45	1.4
0.636	0	0.364	−38	1.345
0.591	0	0.409	−32	1.302
0.88	0	0.12	13	1.599
0.85	0	0.15	4	1.574
0.825	0	0.175	−5	1.549
0.8	0	0.2	−13	1.527
0	0.35	0.65	−35	1.133
0	0.5	0.5	−48	1.192
0	0.7	0.3	−41	1.284
.763	.027	.210	−26	1.503
−709	.050	.241	−32	1.468
.662	.070	.268	−38	1.443
.620	.088	.292	−42	1.422
.763	.038	.198	−22	1.506
.709	.070	.221	−33	1.481
.662	.100	.236	−38	1.456
.620	.125	.255	−41	1.439
.584	.147	.269	−43	1.421
.544	.171	.285	−45	1.404
.522	.184	.293	−50	1.394

The freezing point data of Table I were statistically analyzed and fitted to a cubic model, using the commercially available computer program STATGRAPHICS. Statistical analysis and response surface modeling of this sort is well known in the art. A ternary composition response surface diagram of freezing points for those compositions of the present invention having only the three ingredients is presented as FIG. 1. It is evident from the data presented that the freezing points of compositions of the present invention are not readily predictable from only a few data of widely spaced points on the ternary response diagram. The freezing point properties of these compositions could not have been predicted using current methods of the art without experimentation. However, by obtaining sufficient data on a variety of compositions, one skilled in the art should be able to identify compositions of the present invention having freezing points below −5° C. or alternatively below −40° C., as desired. For example, a freezing point of −5° C. might be suitable for space flight applications, but a freezing point of −40° C. might be desirable for military applications in harsh environments.

The density data of Table I were likewise analyzed and fitted to a quadratic model. A ternary composition response surface diagram of densities of compositions of the present invention is presented as FIG. 2. By suitable experimentation, one skilled in the art should be able to identify compositions of the present invention with densities above 1.3, or alternatively above 1.4. The density of an energetic composition is an important parameter in the performance of the composition in propellants, with greater density generally allowing greater energy content per unit volume.

Another advantage of the present invention is the customizability of the formulation. In particular, by adjusting the water content of the final formulation, the combustion temperature can be adjusted to give a desired flame temperature or to achieve specific physical/chemical/safety properties. For example, this can reduce the vulnerability characteristics and the corrosivity/erosion problems associated with the exhaust gases.

Another advantage of the present invention is cost. Hydrogen peroxide, in particular, is relatively inexpensive.

In addition to the hydrogen peroxide, hydroxylammonium nitrate and water, compositions of the present invention may also contain additives to modify other properties of the gas-generating liquids. These additives usually total less than 1 percent by weight of the composition. For example, the composition may contain a colorant. This is a dye which allows the gas-generating liquid to be more easily seen. This is particularly useful, for example, in locating spills.

Another additive which may be used is an odorant. This is a compound with an odor readily detected by the human nose, and is generally used for detecting and locating spills.

Another additive which may be used is a stabilizer. This will usually be an oxygen scavenger, such as ammonium thiosulfate, which serves to slow chemical degradation of the gas-generating liquid.

Another additive which may be used is a chelating agent, such as ethylenediamine tetraacetic acid (EDTA) or cyclohexanediaminetetraacetic acid (CDTA) or sodium salts of these compounds. Chelating agents serve to bind impurity metal ions in the liquid, and can serve to slow degradation of the gas-generating liquid.

Another additive which may be used is a gelant, or gelling agent. Having the gas-generating liquid in gel form may be useful in certain applications.

Another additive which may be used is a thixotropic agent. Such an agent can improve the general handling properties of the liquid, such as pumping or pouring.

Another additive which may be used is a burning rate modifier. Such an additive affects the kinetics, or rate of burn of compositions.

Another additive which may be used is a surfactant. Surfactants can serve to allow miscibility of the gas-generating liquid with certain fuels. Also, a surfactant can serve to modify the droplet size of the gas-generating liquid when it is sprayed, for example into a rocket combustion chamber.

The compositions of the present invention may be used as liquid oxidizers for a variety of propellant systems. In general, propellant systems are monopropellant or bipropellant systems.

In theory, a liquid monopropellant is the ideal energy source for various liquid gas generator applications such as gun propellants, air bag inflators, torpedo propulsion and rocket motors. The monopropellant's main advantage is simplicity when compared to liquid bipropellant systems: a monopropellant requires only half the number of pumps, valves, storage tanks and pipes. An example of a monopropellant is the nitrate ester-based Otto fuel used in torpedoes.

When used as a monopropellant, a composition of the present invention would generally be preblended with a fuel. Such a fuel could be a water-soluble fuel, in which case the fuel would generally dissolve in the liquid oxidizer. Non-water soluble fuels, such as hydrocarbons, may also be used. Monopropellants using hydrocarbons and the liquid oxidizers of the present invention would generally be emulsified mixtures. In some cases, surfactants may be added to allow for better emulsification. Among the fuels that may be used

with the invention are alkylammonium nitrates and alkanolammonium nitrates having one, two or three carbon atoms.

Monopropellants made using the liquid oxidizer of the present invention may be used for other purposes. If the oxidizer containing hydrogen peroxide, ammonium nitrate and water is mixed in appropriate ratio with a fuel, for example urea, an alkylammonium nitrate or hydrocarbon, the decomposition reaction can in theory yield nitrogen, carbon dioxide, carbon monoxide and water. Such a decomposition mixture would not support combustion, and might be usable in air-bag inflation, fire suppressant or related uses.

In practice, most liquid propellant systems use bipropellants. One problem with some liquid monopropellants is the low energy content of the monopropellant, in order to meet physical, chemical and safety requirements. If the oxidizer and fuel are separated, the sensitivity to shock, friction and static discharge are reduced. The homogeneous mixture of the two components of a liquid propellant has a sensitivity which is greater than that of either component.

Bipropellant systems are commonly used in rocket motors. In a bipropellant system, the liquid oxidizer contacts the fuel at the time of combustion. Rocket motors may use liquid fuel, or in the case of hybrid rocket motors, the fuel may be solid. The compositions of the present invention may be usable as liquid oxidizers for both kinds of rocket motors. Metallic additives may be added to these fuels to improve the propellants' energy outputs.

In Table II, below, are tabulated theoretical performance data for a bipropellant systems with a PERHAN oxidizer composition of the present invention, mixed with JP-10 fuel in the indicated oxidizer-to-fuel ratio. For comparison, a bipropellant using a mixture of HAN water having the same water content as the composition of the present invention is also tabulated. The bipropellant based on the PERHAN composition of the present invention is calculated to have a greater than 15% increase in energy over the HAN/water composition, based on C* values.

Although the oxidizer composition of the present invention is more energetic, this composition has a lower freezing point and is expected to be less expensive than the HAN/water composition.

TABLE II

Theoretical Performance Data for a Selected Bi-Propellant H_2O_2-Hydroxylammonium nitrate-Water ("PERHAN")/JP-10 System

Oxidizer Formulation			Oxidizer To Fuel	Chamber Temp	Pressure		
% HAN	% H_2O_2	% H_2O	Ratio	[illegible]	[illegible]	Isp	C*
[illegible]	12.5	25.5	[illegible]	[illegible]	[illegible]	341	4554
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4486

In general, catalytic or thermal combustion of an oxidizer composition of the present invention with low-carbon content fuel should generate an exhaust gas containing N2, H_2O, and some CO_2. Catalytic or thermal combustion of an oxidizer composition of the present invention should generate an exhaust gas containing N_2, H_2O, CO_2, CO, CH_4 and other gases. However, no HCN is expected in the exhaust gas, unlike exhaust gases resulting from nitrate ester fuels.

The compositions of the present invention may also be decomposed to yield gases and energy. This decomposition may be achieved by catalysis. For example, placing the composition of the present invention in contact with a fixed bed catalyst, such as Pt, Pd, or MnO_2, may yield decomposition. Such a reaction is well known in the art for other liquids, for example, hydrogen peroxide decomposing to water and oxygen. Alternatively, the composition of the present invention might by decomposed by adding a catalyst to the composition to dissolve or suspend the catalyst. This may be done in a catalyst stream flow process. For example, the composition of the present invention and a catalyst could be delivered from a bladder and mixed upon delivery, by methods known in the art.

Alternatively, decomposition of a composition of the present invention may be achievable by heating the composition. If, for example, the composition is injected into a hot reaction chamber, the heat of decomposition may be sufficient to self-sustain the decomposition reaction, and a continuous decomposition of a stream of the composition may be possible.

One possible application of decomposition of compositions of the present invention is in breathable air generators. Hydroxylammonium nitrate and hydrogen peroxide may be theoretically decomposed to oxygen, nitrogen and water according to the following stoichiometries:

$$NH_3OHNO_3 \rightarrow O_2 + N_2 + H_2O \quad (1)$$

$$H_2O_2 \rightarrow 0.5O_2 + H_2O \quad (2)$$

Therefore, compositions of the present invention containing hydrogen peroxide, hydroxylammonium nitrate, and water can theoretically be decomposed into oxygen, nitrogen and water. Such a decomposition could be used to create a gas mixture which could be used for breathable air. Unlike chlorate-based systems, the present invention would provide a mixture of oxygen and nitrogen, which may be better for use as breathable air at atmospheric pressure than pure oxygen. Moreover, the present invention would yield no chlorine, which is a byproduct of chlorate candle systems.

In Table III, below, are tabulated the theoretical performance data as an oxygen generator for the composition of the present invention from Table II, and for a HAN/water composition for comparison. The composition of the present invention has approximately 9.4% more available oxygen than the HAN/water composition of the same water content, and the two compositions can be seen to have similar energy outputs. The composition of the present invention has a 10° C. lower freezing point than the comparable HAN/water composition, which may allow the present invention to be usable under extreme weather conditions.

chemicals is extremely low in the compositions, and skin toxicity is also expected to be relatively low.

The preparation of the compositions from the constituent ingredients is relatively simple and safe, as the dissolution of the ingredients is generally an endothermic process. And, due to the water solubility of the components, water can be used in the cleanup of spills. The compositions of the invention should be readily chemically degradable or biodegradable, simplifying disposal of the compositions. The compositions of the present invention may be considered to be "green," that is, not a hazard to the environment.

Thus, the compositions of the present invention have a number of significant advantages over liquid oxidizers and other gas-generating compositions in present use.

As will be evident to those skilled in the art, various combinations and modifications can be made in light of the foregoing disclosures without departing from the spirit or scope of the disclosure. It is, therefore, to be understood that within the scope of the appended claims the invention may be practiced otherwise than as specifically described.

What is claimed is:

1. A water-based, gas-generating liquid, comprising:
hydrogen peroxide;
hydroxylammonium nitrate; and
water.

2. The gas-generating liquid of claim 1, said water being at a concentration in the range of approximately 10 to 50 w/w-%.

3. The gas-generating liquid of claim 2, said water being at a concentration in the range of approximately 15 to 30 w/w-%.

4. The gas-generating liquid of claim 1, said hydroxylammonium nitrate being at a concentration in the range of approximately 20 to 70 w/w-%.

5. The gas-generating liquid of claim 4, said hydrogen peroxide being at a concentration in the range of approximately 15 to 50 w/w-%.

6. The gas-generating liquid of claim 4, said hydroxylammonium nitrate being at a concentration in the range of approximately 30 to 60 w/w-%.

7. The gas-generating liquid of claim 1, said hydrogen peroxide being at a concentration in the range of approximately 15 to 50 w/w-%.

8. The gas-generating liquid of claim 7, said hydrogen peroxide being at a concentration in the range of approximately 25 to 40 w/w-%.

9. The gas-generating liquid of claim 1, said gas-generating liquid being characterized by having a freezing point below −5° C.

TABLE III

Oxygen Gas Generator Theoretical Performance Data for a Selected H_2O — Hydroxylammonium nitrate-Water ("PERHAN") Composition

Oxidizer Formulation			Chamber Temp	Impulse	RF		Exhaust Gas Composition, mole fraction				Freezing	Density
% HAN	% H_2O_2	% H_2O	Tc F	Isp	Isp	C*	H_2O	N_2	O_2	NO_x	Point, °C	g/cc
[illegible]	12.5	25.5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.63	[illegible]	[illegible]	1.439
75.2	[illegible]	24.8	[illegible]	[illegible]	[illegible]	24.4	[illegible]	[illegible]	0.78	[illegible]	[illegible]	[illegible]

In addition to the described functional properties, the compositions of the present invention also have excellent handling and safety characteristics. Because they are non-cryogenic, the problems associated with cryogenic materials are avoided. Corrosivity is also expected to be relatively low, simplifying storage and handling. Due to the water content and the use of protonated salts, the vapor pressure of toxic

10. The gas-generating liquid of claim 9, said gas-generating liquid being characterized by having a freezing point below −40° C.

11. The gas-generating liquid of claim 1, said gas-generating liquid being characterized by having a density above about 1.3.

12. The gas-generating liquid of claim 11, said gas-generating liquid being characterized by having a density above about 1.4.

13. The gas-generating liquid of claim 1, further comprising a stabilizer.

14. The gas-generating liquid of claim 1, further comprising a chelating agent.

15. The gas-generating liquid of claim 1, further comprising a fuel.

16. The gas-generating liquid of claim 15, said fuel being a hydrocarbon fuel.

17. The gas-generating liquid of claim 16, further comprising a surfactant for solubilizing the hydrocarbon fuel or for adjusting the droplet size of the liquid.

18. The gas-generating liquid of claim 15, said fuel being an alkylammonium nitrate or alkanolammonium nitrate having one, two or three carbon atoms.

19. A water-based, gas-generating liquid, consisting essentially of:

hydrogen peroxide;

hydroxylammonium nitrate; and

water.

20. The gas-generating liquid of claim 19, said water being at a concentration in the range of approximately 10 to 50 w/w-%.

21. The gas-generating liquid of claim 19, said hydroxylammonium nitrate being at a concentration in the range of approximately 20 to 70 w/w-%.

22. The gas-generating liquid of claim 19, said hydrogen peroxide being at a concentration in the range of approximately 15 to 50 w/w-%.

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